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A Tool for Verification of Big-Data Applications

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DICE
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Our work at a glance

- Approach and tool for the automated verification of topology-based data-intensive applications.
  - Based (so far) on temporal logic model
  - Performs automated transformation from high level application description to formal model
  - Enables verification of safety properties

Roadmap

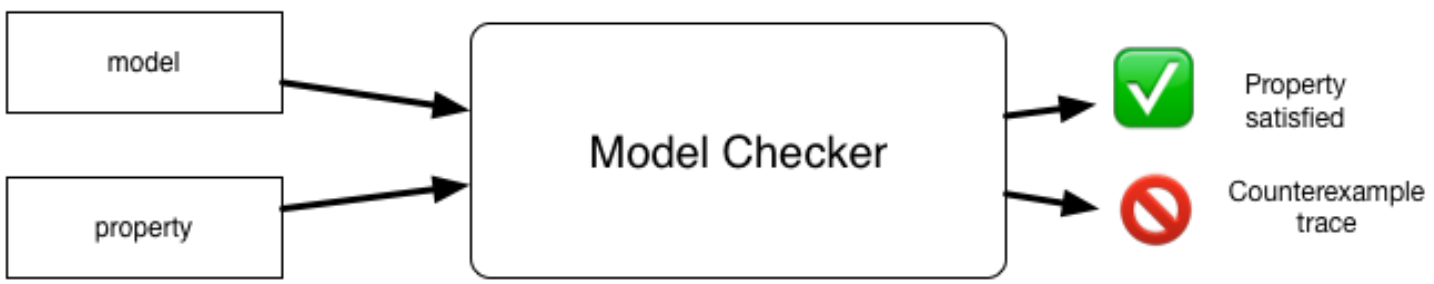
- *Context*
  - *Quality assurance in DIA*
- *Research Design*
  - *Research question*
  - *Our approach*
- *Conclusions*
  - *Contributions*
  - *Future works*

Quality Analysis and Verification for data-intensive applications

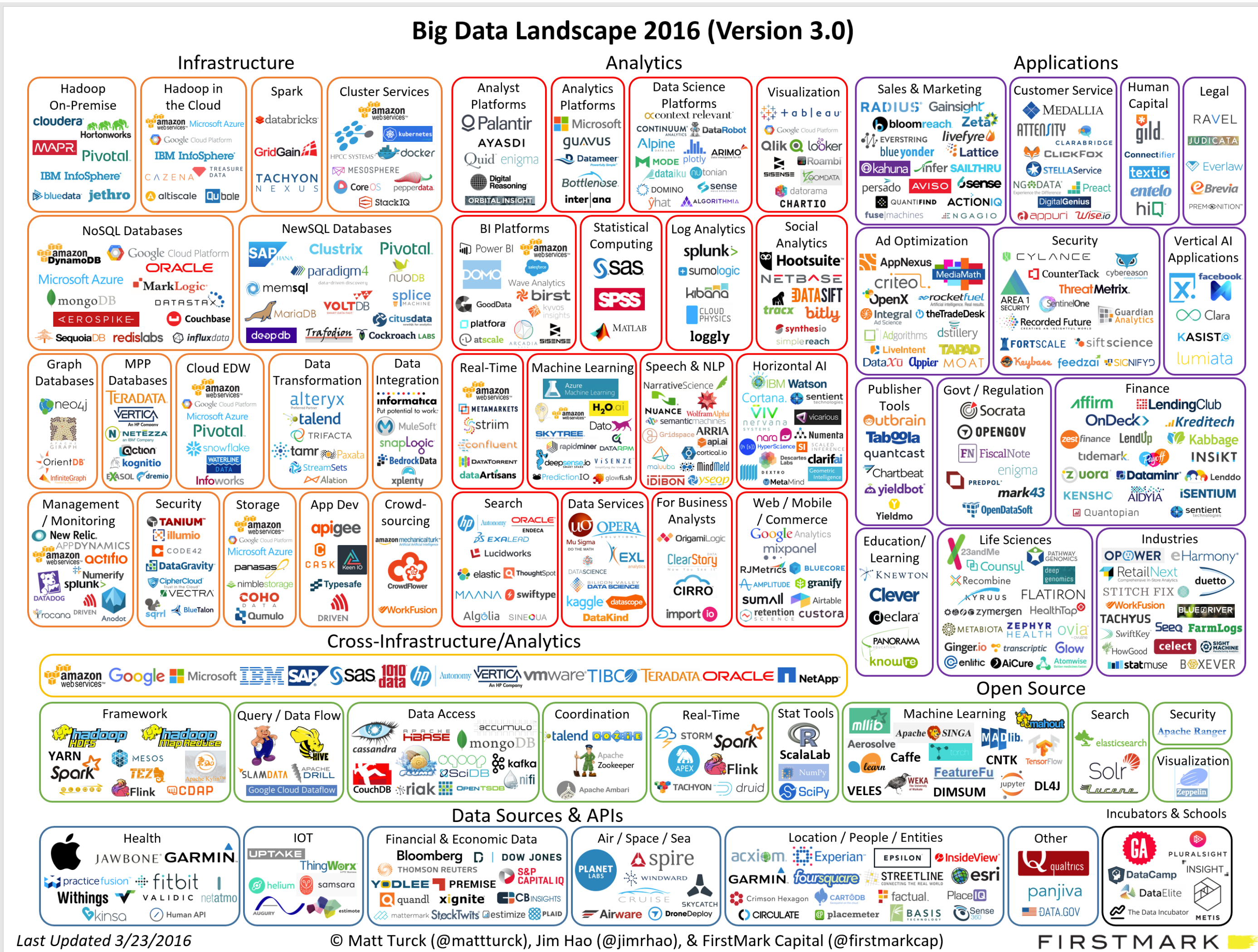
CONTEXT

Formal Verification

- Given a Model M and a Property specification P, verification checks whether P holds in M.
- M and P can be expressed in many different ways
  - various kinds of automata (operational models)
  - various kinds of logics (descriptive models)



Data-Intensive Applications (DIA)



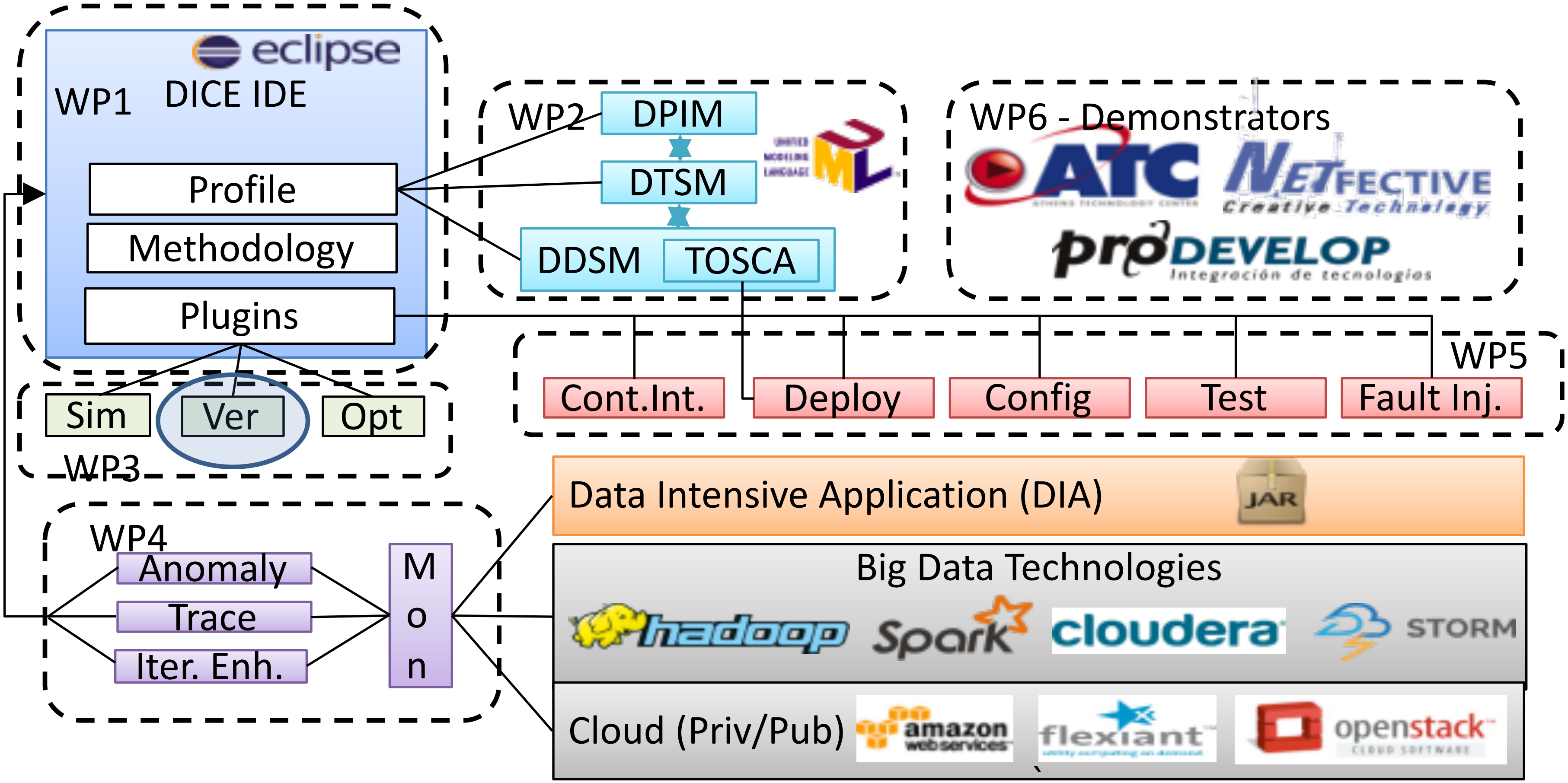
DICE Project

- Horizon 2020 Research & Innovation Action (RIA)
  - Quality-Aware Development for Big Data applications
  - Feb 2015 - Jan 2018, 4M Euros budget
  - 9 partners (Academia & SMEs), 7 EU countries

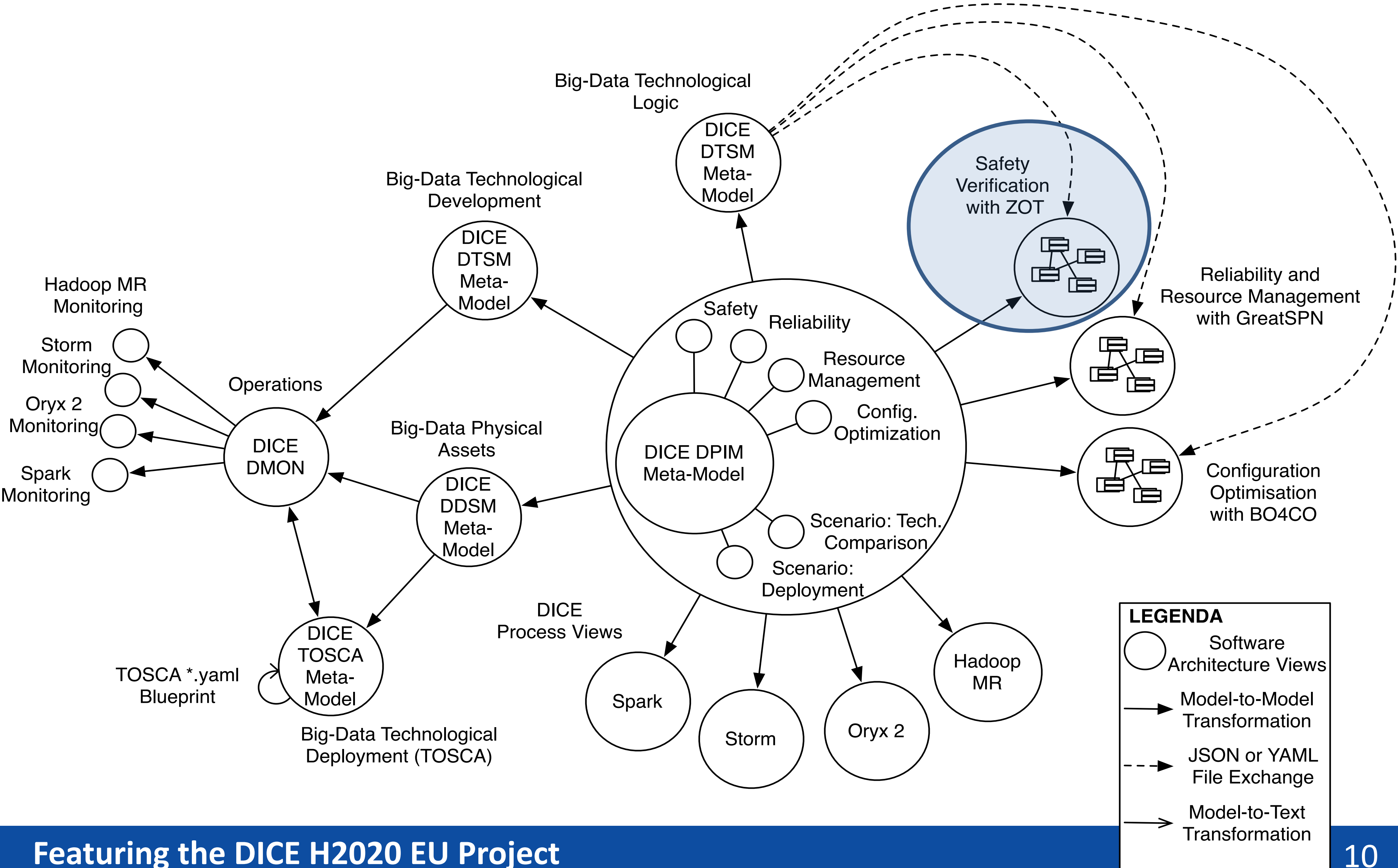
Quality Dimensions in DICE

- Reliability
  - Availability
  - Fault-tolerance
- Efficiency
  - Performance
  - Costs
- Safety & Privacy
  - Verification
  - Data protection

Our positioning in DICE framework (1)



Our positioning in DICE framework (2)



Quality Analysis and Verification for data-intensive applications

RESEARCH DESIGN

Research question

"How can we verify safety properties of a data-intensive application?"

State of the art

- Formal verification of distributed systems is a major research area in software engineering
- Few works trying to address formal verification in the context of DIA
  - Main focus on verifying *application-independent* properties related to specific frameworks
    - Reliability and load balancing of MapReduce
    - Validity of messaging flow in MapReduce
  - no modeling and verification of *application-dependent* properties
- Verification tools have been used as verification engines to build formal verification techniques for UML models
  - Few of them deal with real-time constraints.
  - Mainly focused on functional requirements.

Our Approach

- Focus on a specific set of technologies
  - Topology-based streaming applications → **Apache Storm**
- Identify safety issues
- Devise a formal model
  - Having an appropriate level of abstraction
  - Allowing to capture meaningful system behavior and properties
  - Using a formalism that enables automatic verification
- Define a tool-supported mechanism for formal verification
  - Starting from high level application description (annotated UML)

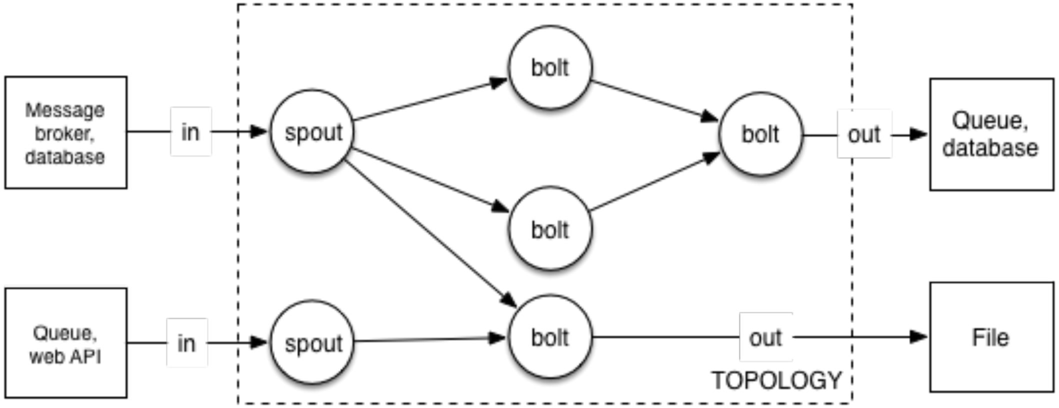
Apache Storm

- Open Source Distributed Stream Processing System
- Analytics, Log Event processing, etc..
- Reliability, at-least-one semantics
- Wide adoption in production
- Main concepts
  - Streams
  - Topologies

STORM

Storm Applications

- Applications defined by means of **Topologies,** graphs of computations composed of:
  - **Spouts**
    - Sources of data streams (tuples)
  - **Bolts**
    - Calculate, Filter, Aggregate, Join, Talk to databases



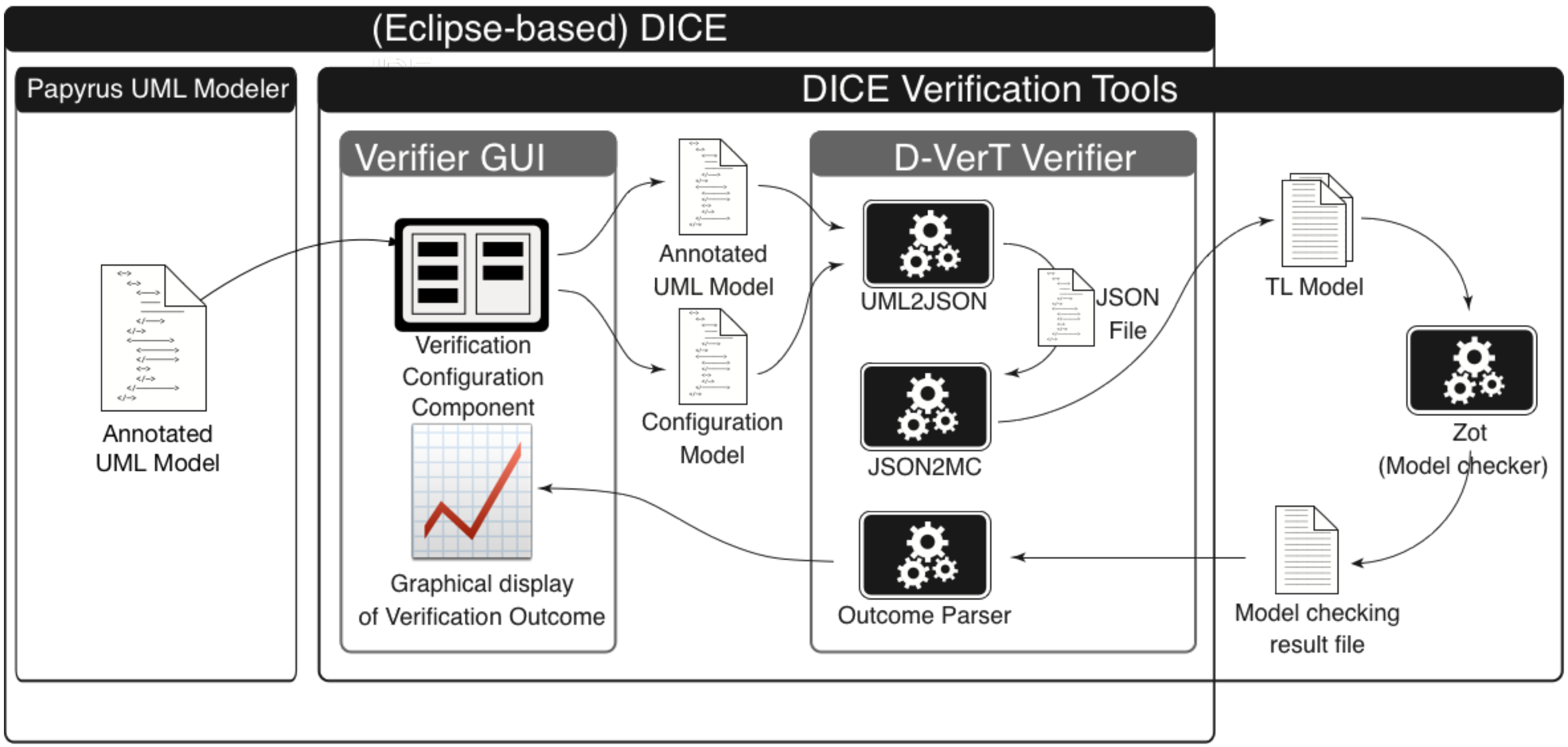
Safety Issues

- Important requirements for streaming applications
  - **Latency**
  - Throughput
- Critical points
  - incorrect design of timing constraints
  - node failures
- might cause
  - latency in processing tuples
  - monotonic growth of the size of used memory (queues).

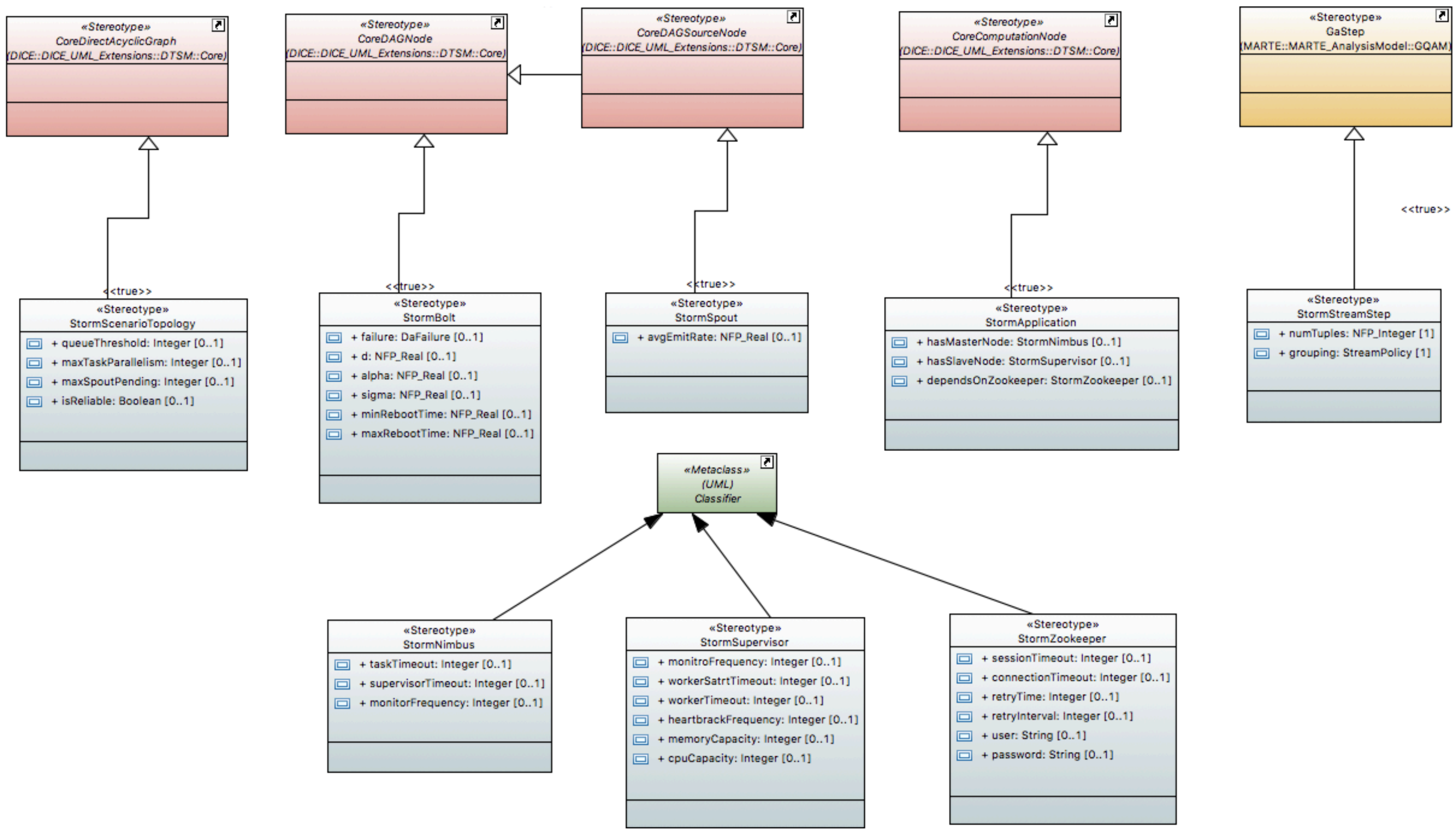
DICE Verification Tool

- We want to
  - Verify whether a topology reaches an **unwanted configuration**
    - e.g., where bolts are not able to process incoming tuples on time
  - Let the user specify the topology by means of high level models (UML)

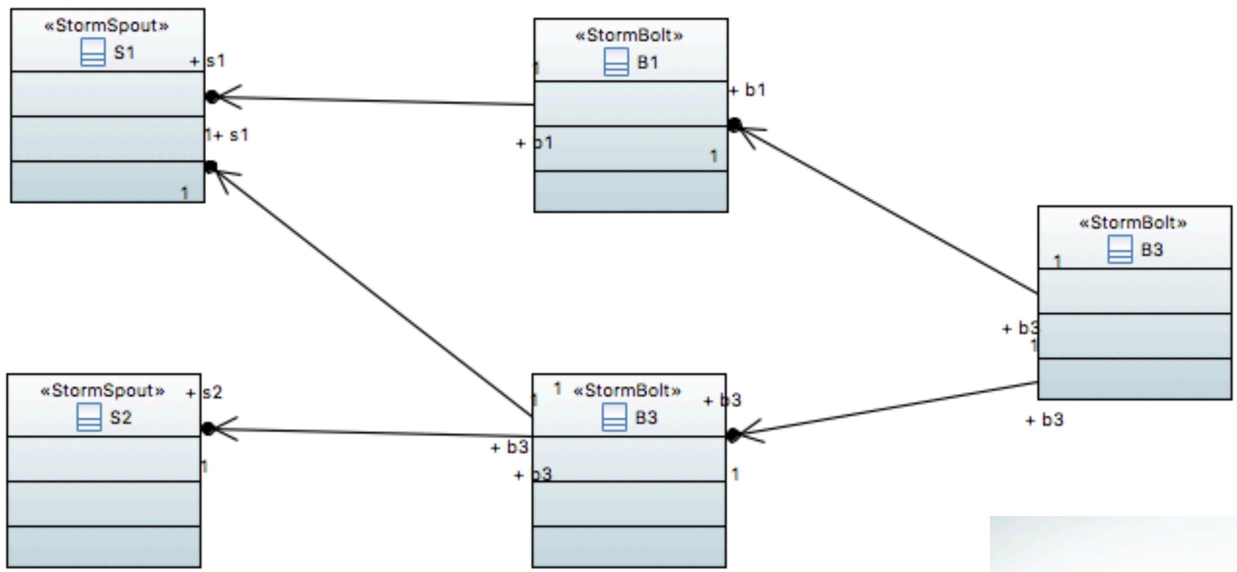
D-VerT - DICE Verification Tool



DICE DTSM::Storm UML profile

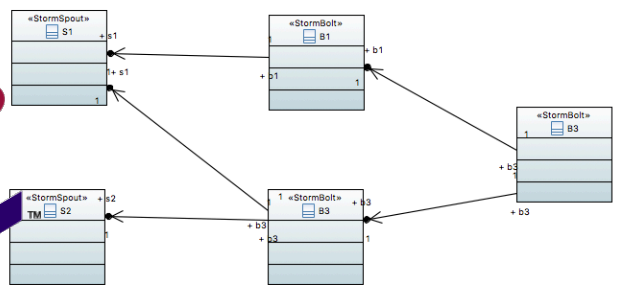


D-VerT - DICE-profiled UML Class Diagram



DTSM2Json module

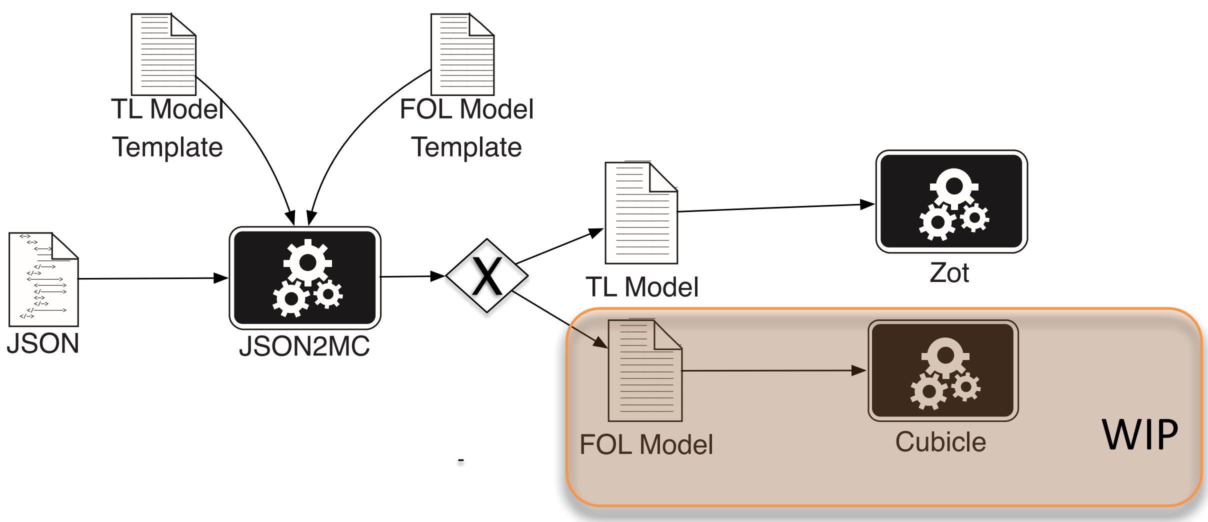
- Relies on Eclipse **UML2** Java library
- “Navigates” DTSM class diagram and extract topology structure and information
- Gathers verification option from Eclipse launch configuration
- Maps topology components to Java objects
- Directly converts Java objects to JSON object via **gson** library




```
{
"app_name": "SIMPLE-DIA-TOPOLOGY",
"version": "0.1",
"topology":
{
"spouts":
[
   {"id":"S1",
   "parallelism": 5,
   "avg_emit_rate":1.0},
   {"id":"S2",
   "parallelism": 5,
   "avg_emit_rate":1.0}
],
"bolts":
[
   {"id":      "B1",
   "subs":    ["S1"],
   "alpha":   5.0,
   "sigma":   2.0,
   "parallelism": 5},
   {"id":      "B2",
   "subs":    ["S1","S2"],
   "alpha":   5.0,
   "sigma":   0.5,
   "parallelism": 10},
   {"id":      "B3",
   "subs":    ["B1", "B2"],
   "alpha":   1.0,
   "sigma":   1.0,
   "parallelism": 1}
],
"min_reboot_time":10,
"max_reboot_time":100,
"max_idle_time": 0.01,
"init_queues":0,
"queue_threshold": 20
},
"verification_params":
   {"plugin" :["ae2sbvzot"],
   "max_time" : 20000,
   "num_steps":15,
   "periodic_queues":["B1","B2","B3"],
   "strictly_monotonic_queues":["B1","B2","B3"]}
```

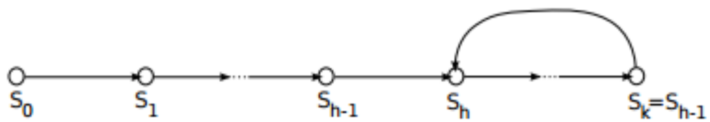
Json2MC - Module

- Python component based on Jinja2 templating engine
- Generates Formal Model based on the content of JSON file and on the selected template (TL or FOL).



Verification Approaches

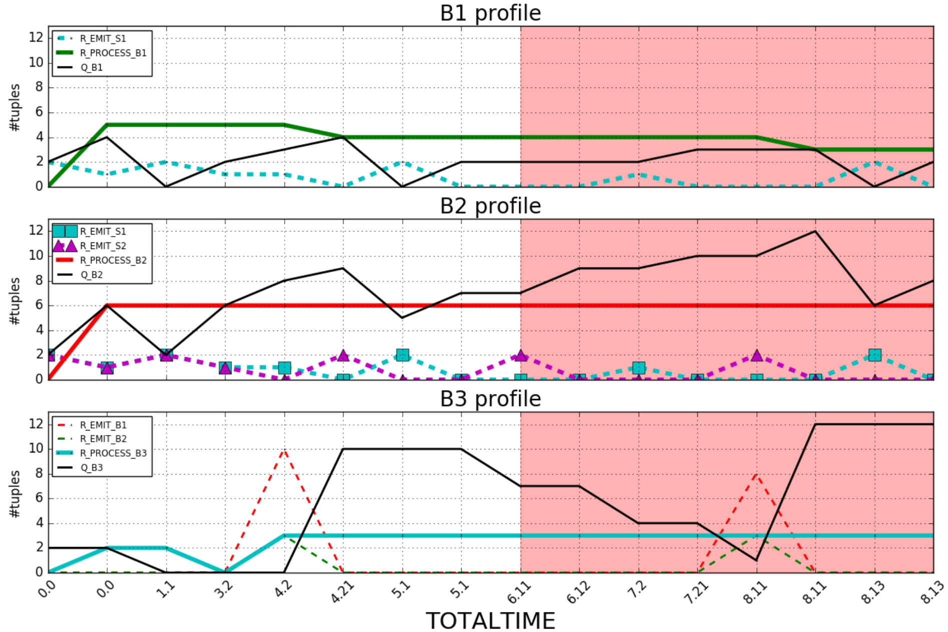
- Bounded Satisfiability Checking (BSC)
  - Input:
    - Temporal logic formula (Model)
    - Negated Property over time



  - Outcome:
    - SAT → counterexample trace
    - UNSAT → Property holds for the considered time bound
  - We use **Zot** verification tool (https://github.com/fm-polimi/zot)
- Reachability Checking (WIP)
  - Model defined by FOL Array based system
    - Set of **initial states** and **transitions**
    - Formula defining **undesired states (Negated property)**
  - Outcome:
    - UNSAFE → Trace showing that undesired state are reachable from initial states
    - SAFE → No undesired state can be reache from initial states

D-VerT – Output trace

- When at least one queue grows with an unbounded trend
  - an infinite ultimately periodic model is found
  - **Output Parser** provides graphical counterexample trace



CONCLUSIONS

Contributions

- We enabled automatic verification on *topology-based* streaming applications by
  - Defining a formal model based on temporal logic
  - defining automatic mechanisms for translating to the formal model from a high level description.
  - extending Zot Verification tool to support the formalism and carry out BSC on it

Preliminary results

- Validation through open source and industrial use cases
  - Meaningful qualitative results in identifying critical points in topology design
  - Execution time strongly depends on the size of the topology and on the configurations of single components

Topology	Bolts	Time	Max Memory	Outcome	Spurious
simple-DIA-cfg-1	3	60s	104MB	SAT	no
simple-DIA-cfg-2	3	1058s	150MB	UNSAT	N/A
focused-crawler-complete	8	2664s	448MB	SAT	no
focused-crawler-reduced-cfg-1	4	95s	142MB	SAT	no
focused-crawler-reduced-cfg-2	4	253s	195MB	SAT	no
focused-crawler-reduced-cfg-3	4	327s	215MB	SAT	no
focused-crawler-reduced-cfg-4	4	333s	206MB	SAT	no
focused-crawler-reduced-cfg-5	4	3184s	317MB	SAT	yes
focused-crawler-reduced-cfg-6	4	1060s	229MB	SAT	yes

http://dice-project.github.io/DICE-Verification/

Ongoing and Future works

- Identification and verification of further properties
  - Privacy and Security
- Tool improvements
- Modeling different technologies (Spark, CEP, Tez)
- Developing FOL model
- New theoretical results on the correctness and completeness of the formal analysis

Questions?

Thank you!